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REDUCING TRAFFIC CONGESTION IN MODERN CITIES: A CHALLENGE BASED ON PHYSICO-MATHEMATICAL THEORIES AND WIRELESS SENSOR NETWORK

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ABSTRACT

During the last decade, the ever increasing number of vehicles has worsened the traffic congestion which has become a hot topic in large urban areas. The solution to reduce this congestion in modern cities is based on the optimization of light signals through communication between the wireless sensor placed on each lane and the traffic light controller. It leads to phase duration changes implied by traffic demand. To be more exhaustive, the traffic control at crossroads aims at therefore determining the sequences of vehicles crossing i.e. the distribution sequences to enjoy the right of crossing (green traffic light). This new strategy of traffic control has plentyof potentialities to exploit the abilities of the intersection. Through this article, we will take into account the parameters to diminish the effects of the congestion traffic, as we get on a physico-mathematical model so as to increase the flow of road traffic and avoid road traffic and congestion.

***KEYWORDS:** Traffic Congestion, Modern Cities, Physico-Mathematical Model, Debit & Wireless Sensor Network*

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Original Article

INTRODUCTION TO ROAD TRAFFIC

The ever increasing population in great cities has raised the number of vehicles which consequently resulted in great deals of traffic jams [1-4]. They nowadays represent millions of wasted hours and the economic losses in the costs implied the strong exposure to pollution coming out of the exhaust pipes on the one hand and the stressing, mental and physical consequences due to waiting lines, and the hiccups of road traffic. This phenomenon has become one of the main problems to solve through nowadays regulation systems [5]. We talk about congestion traffic, that is why a fluent traffic in the urban networks, and the development of technologies in computer science and telecommunications.

Many new technologies in traffic regulation have been referred to in [6-11] e.g. the wireless communication technologies- wireless sensor network [10, 12-21]. In order to provide answers in road traffic regulation, we will start by going through different variables that make it possible to understand phenomena of appearance or resorption of congestion at an intersection before defining the number of cars included in the waiting line which are comprised between the two sensors placed on each lane.

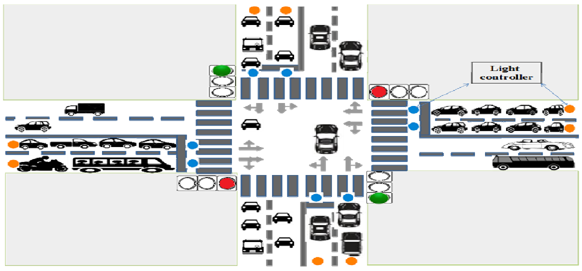
Later, we will present physico-mathematical theories which make it easy to calculate the out flow of the road in case the traffic is heavily saturated, we will also define a regulation method by the traffic lights and the communication between the wireless sensor and the light controller in order to find out an optimal sequence to

allow vehicles through.

PAGE LAYOUT

Topology of Infrastructure: a Simple Intersection

The intersection model, our survey is based on, is shown in Fig. 1



Index	Single Intersection Road Network
	Traffic light
	Communication between the sensor and the light controller
	C_1 sensor placed before the traffic light
	C_2 sensor placed after the traffic light

Figure 1: Traffic WSN Complete Architecture

It implies four directions and each of these are divided into two incoming lanes and two outbound ones. Thus, four traffic lights are set at the end of the intersection. Each lane is fitted with two wireless sensors C1 and C2, the first is placed before the traffic lights and the second one is placed after. X is the distance between the two sensors.

For each step, a light controller defines, one or several movements getting the green light as well as the duration of the step starting from the communication between the wireless sensor and the traffic light controller. It is often considered, in literature that each incoming lane is equipped with two sensors: one is located by the light so as to count the departures and the other is at a set distance in order to count the arrivals. The distance between these two sensors is variable and it has to be long enough to measure the evolution of the waiting line.

The Variables Used to Describe the Road Traffic

Road Measurement Units

Table 1: Road Measurements

Measurement	Notation	Unit of Measurement
The number of vehicles	N	*veh*
Length of the vehicles (Average)	L_{veh}	*m*
Number of lanes	l	-
Distance between two sensors C_1C_2	X	*m*
Speed of vehicle	v	*m/s*
Time	T	*m*
Time of reaction	t_r	*m/s*
Distance of reaction	d_r	*m*
Road flow	Q	*Veh/h*
Road density	ρ	*Veh/m*
Kinetic energy	E_c	*J*
Braking distance	d_c	*m*
Constant braking	$1/2.k.m$	s^2/m
Stopping distance:(Safety distance)	d_s	*m*

($d_s = d_r + d_f$)		

The Traffic Parameters: Some Definitions

- **Number of vehicles N:**

  The number of vehicles ***N*** which covers the distance ***X*** between the two sensors located on each lane is given by the formula:

$$N = \frac{X}{L_{veh} + d_s} \tag{1}$$

With L_{veh} as the length of the vehicles and d_s is the stopping distance (Security):

$$d_s = d_r + d_f \tag{2}$$

- The reaction distance d_r is defined as the distance covered by the vehicle between the moment when the conductor sees the obstacle and the time when he starts braking. It is proportional to the reaction time t_r, the driver and the speed, ***v*** of the vehicle. It is given through the formula:

$$d_r = v t_r \tag{3}$$

- The reaction time t_r for a driver is defined as the time that elapses between the perception of an obstacle by the driver and his or her reaction. The average reaction time for a driver who is in good shape is one or two seconds for a tired driver, but 2 to 3 seconds for a driver under the effects of an alcoholic beverage.
- The braking distance, d_f is defined through the distance covered by the vehicle between the moment when the driver uses the brakes and the time when the vehicle stops. It depends on the vehicle speed, ***v***, the mechanic state of the vehicle (brakes, tyres) as well as state of the road under the weather (rain, drought and ice,).

To handle simpler calculations, the conditions neither those of the vehicle nor those of the road are taken into account. Therefore, the braking distance, d_f, depends on the speed and is not proportional to the speed. Actually d_f, depends on the kinetic energy of the vehicle and therefore depends on v^2 and not on ***v***:

$$d_f = \frac{1}{2}.k.mv^2 \tag{4}$$

The speed of the vehicles ***v*** is given by:

$$v = \frac{X}{T} \tag{5}$$

In reference to (1), (2), (3), (4) and (5) we get the number of vehicles according to the speed and the length of the vehicle:

$$N = \frac{vT}{L_{veh} + v t_r + \frac{1}{2}.k.mv^2} \tag{6}$$

- The flow $\boldsymbol{Q}$ between the two sensors placed on each lane of the intersection is the number of vehicles $\boldsymbol{N}$ which, at a constant speed, crosses sensor $\boldsymbol{C_1}$ placed, before the traffic light per unit of time $\boldsymbol{T}$. The mathematical expression of the flow on the track becomes:

$$Q_{(number\ of\ vehicles\ per\ hour)} = \frac{N_{(number\ per\ of\ vehicles)}}{T_{(hour)}} \tag{7}$$

According to (6) and (7), we get:

$$Q = \frac{v}{L_{veh} + v\,t_r + \frac{1}{2}.k.mv^2} \tag{8}$$

We can trace the flow curve $\boldsymbol{Q}$ depending on the speed $\boldsymbol{v}$ (the data related to the vehicle length and the reaction time are supposed to be two constant values). This representation is shown in Fig. 2

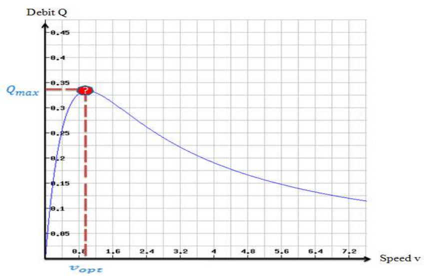


Figure 2: Speed (V) Evolution as a Function of the Flow (Q)

It is noticeable that the road flow, being in a traffic saturation state, varies according to the speed $\boldsymbol{v}$, through a hyperbolic function. The figure displays that when the speed increases, the flow increases until it reaches a maximum thereafter it decreases to tend towards a value equal to zero when the speed tends towards infinity.

Calculation and Characterization of Congestion

And to carry out such calculations, some researchers use equations with partial derivative, equations which allow the description of physical phenomena. For example, the best vehicle flow is obtained, when the following condition is achieved:

$$\frac{dQ}{dv} = 0 \tag{9}$$

So,

$$\frac{d}{dv}\left(\frac{v}{L_{veh} + v\,t_r + \frac{1}{2}.k.mv^2}\right) = 0$$

Therefore, the formula which allows the calculations of the optimal speed $\boldsymbol{v_{opt}}$ is obtained:

$$v_{opt} = \sqrt{\frac{2L_{veh}}{k.m}} \tag{10}$$

So, we can carry out the maximal flow Q_{max}

$$Q_{max} = \frac{v_{opt}}{2L_{veh} + v_{opt} + t_r} \tag{11}$$

Case Study

Formula (10) makes the calculation of the optimal speed feasible in case of a road traffic under saturation. To that extent, we have calculated the average value of the braking constant $\frac{1}{2}m.k$.

Table 2: Braking Constant 1/2.M.K

$v(km/h)$	$v(m/s)$	$v^2(m^2/s^2)$	**Braking Distance D_f (Experimental Value)**	$\frac{d_f}{v_2} = \frac{1}{2}k.m$
50	13.88	192.65	14	0.0726
90	25	625	45	0.072
110	30.55	933.30	68	0.07285
130	36.11	1303.93	93	0.0713
Average value				**0.0721**

SIMULATION TOOL

Green Light District Simulator (GLD)

GLD (Green Light District) [12] is a program that performs discrete simulations of road networks. The full application consists of two parts: an Editor and Simulator. The Editor enables the user to create an infrastructure (a road map) and save it to disk. The simulator can then load the map and run a simulation based on that map. Before starting a simulation, the user can choose which traffic light controller and which driving policy will be used during the simulation (i.e., it specifies traffic-lights green-red policy). In our case, we chose a simple infrastructure (an intersection). A screen shot of the software is available in Fig. 3

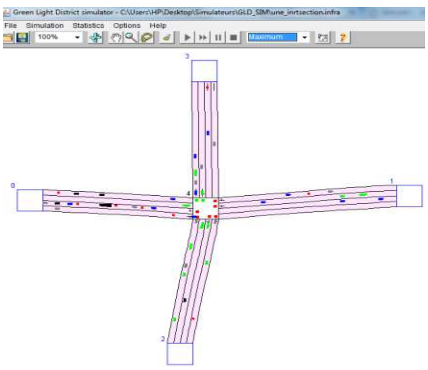


Figure 3: Green Light District Simulator

While performing a simulation (see Fig. 3), different types of statistics are produced. We focus interest on the number of users (road users) Fig. 4 between the two sensors C_1C_2

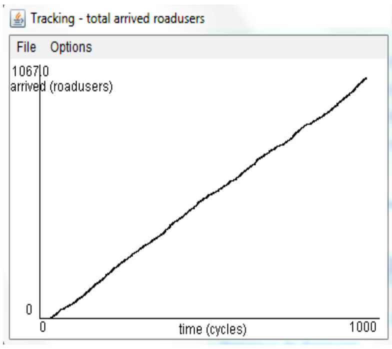


Figure 4: The Number of Road Users as a Graph Presentation

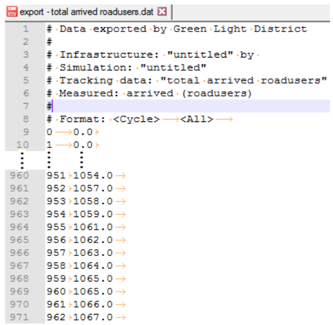


Figure 5: The Number of Road Users a Spreadsheet Form

Fig. 4 shows the number of road users illustrated through the simulation of 1000 cycles.

The cycle being a time unit of GLD, which corresponds to a software movement, such simulations were achieved on an intersection with the input probability of the edge node 0.25

SIMULATION RESULTS AND DISCUSSION

Starting from the values obtained from Fig. 5, we have calculated the average value of car number N_{moy} between the two sensors (the value of X is set to 2000 m):

N_{moy} = 481 (Simulation results)

So,

$$L_{veh_{moy}} = \frac{X}{Nmoy} \approx 4.81m$$

We have not taken account the security distance in the calculation process by introducing the values of the vehicle length L_{veh} and the braking constant $k.m$ in the formula (10):

Therefore the optimal speed:

$$v_{opt} = \sqrt{\frac{2L_{veh}}{k.m}} = 8.16\ m/s \Rightarrow v_{opt} = 29.37\ km/h$$

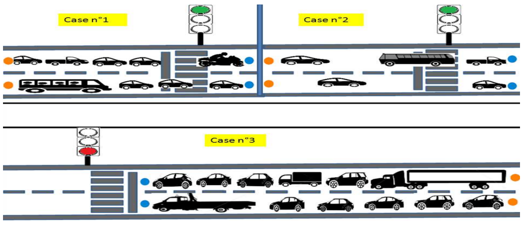
Taking into account hypotheses agreed (t_r= 1s, L_{veh}≈4.81 m), the vehicles need to observe a limited speed set 30 km per hour to reach the maximal flow Q_{max} = 1670 *veh/h*, in order to diminish the effects of the traffic congestion.

CONCLUSIONS AND PERSPECTIVES

The mathematical calculations that we have just carried out show that, in order to achieve the decongestion of the road, the vehicles must define their optimum speeds v and other suitable actions that ought to be taken in order to cross the intersections with minimal delays while at the same time avoid the stops (after their detection by the sensor C_1 placed on the track) and above all keep from changing lanes. If we continue our reasoning and we try to model the traffic congestion in a real world we all of a sudden come up against the complexity of the task because several parameters are not within our command. The driver's behavior. In the phenomenon of the road traffic congestion, the general state of the vehicle (brakes-tyres) and the state of the road (in case of bad weather: humidity, drought, ice on the road). In [18-21] we have already

worked on the communication between the wireless sensors the light controller, in order to reduce the number of transmitted messages.

For the future, we wish to use the parameters referred to before in order; to improve our algorithm previously and optimize the running sequences of the vehicles so as to find out the optimal sequences and the green wave on the most traffic jammed road. That is feasible, thanks to the communicated information provided by the sensor to the traffic light controller about the state of the traffic (according to the three cases dealt with below).



Figure

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